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AN ORBIT PLAN TOWARD AKATSUKI VENUS REENCOUNTER AND ORBIT INJECTION*

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On December 7, 2010, AKATSUKI, the Japanese Venus explorer reached its destination and tried to inject itself into Venus orbit. However, due to a malfunction of the propulsion system, the maneuver was interrupted and AKATSUKI again escaped out from the Venus into an interplanetary orbit. Telemetry data from AKATSUKI suggests the possibility to perform orbit maneuvers to reencounter the Venus and retry Venus orbit injection. Reported in this paper is an orbit plan investigated under this situation. The latest results reflecting the maneuvers conducted in the autumn 2011 is introduced as well.

INTRODUCTION

AKATSUKI, the Japanese Venus explorer, was successfully launched in May, 2010 to investigate the climate and the atmospheric phenomena of Venus. After favorable 200-day interplanetary journey, AKATSUKI arrived at Venus on December 7, 2010. At the arrival, a deceleration maneuver was performed to inject AKATSUKI into the Venus orbit. However, due to a malfunction of the propulsion system, the maneuver was interrupted and AKATSUKI again escaped out from Venus into an interplanetary orbit.

As is shown in Figure 1(a), AKATSUKI orbits around the Sun slightly inside the orbit of Venus. The perihelion radius is approximately 0.62, which imposes on AKATSUKI 40% stronger solar intensity than that expected on the Venus orbit. The mean motion of AKATSUKI is slightly faster than that of Venus, and AKATSUKI go away from Venus to the leading side. When it is viewed on the Sun – Venus line fixed rotational frame, AKATSUKI revolves around the Sun in counterclockwise direction, and finally catch up with Venus some time later (Figure 1 (b)). The orbit period of AKATSUKI was 203 days, which is in the ratio of 10:11 with that of Venus. If any orbit maneuver is not performed, AKATSUKI will re-approach the Venus in the end of 2016 (Figure 1 (c)).

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The telemetry data from AKATSUKI around and after the injection failure suggested the possibility to perform orbit maneuvers to reencounter Venus and retry the Venus orbit injection (VOI). The bipropellant orbit maneuver engine (OME) showed the thrust 75% of its full performance at the end of the injection maneuver. The monopropellant reaction control system (RCS) is healthy and it can be used for the attitude control during the OME firing as well as limited orbit maneuvers. The propellant spent so far was less than 20% of initial amount on board, and most of it still remained. Under this situation, an orbit plan was investigated for AKATSUKI's Venus reencounter (VRE) and VOI, which is the main theme of this paper.

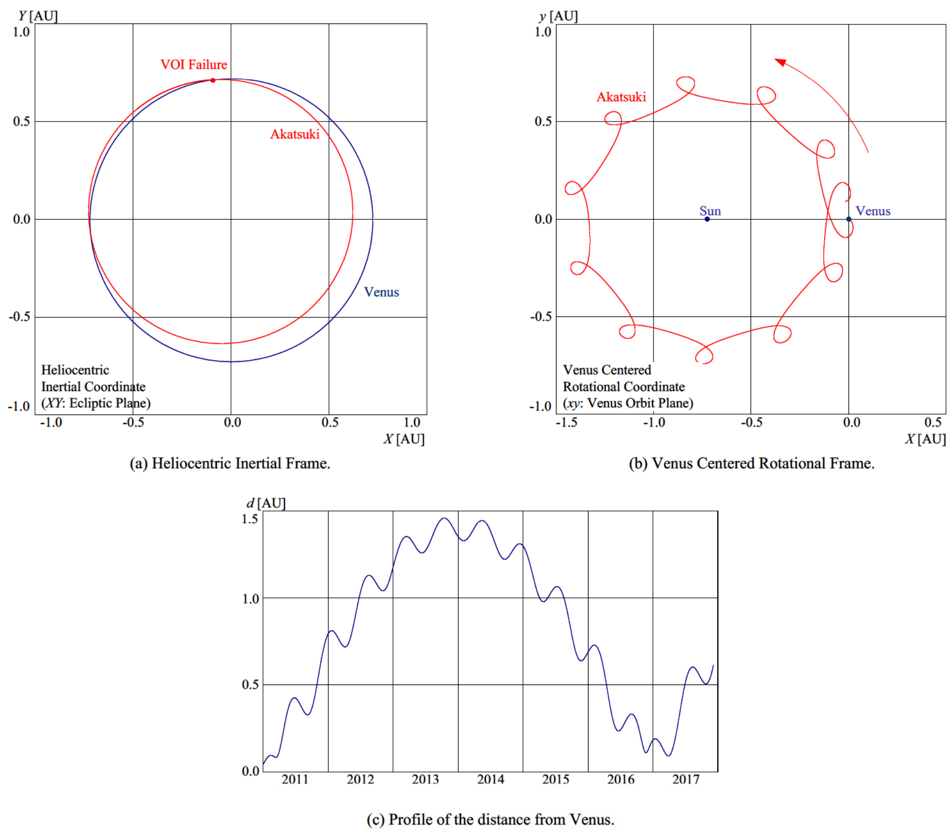

Figure 1. Orbit of AKATSUKI after the Venus Orbit Injection Failure.

The following sections are composed in the way that the actual investigation and operation progressed. First, an orbit to reencounter Venus was planned under the assumption that OME is available. An orbit maneuver plan was mapped out to achieve the injection into the originally planned Venus orbit. According to the plan, orbit maneuvers were performed in autumn 2011 around the second perihelion passage after the VOI failure. Unfortunately, in the test maneuvers preceding the main perihelion maneuvers, OME turned out to be out of use. The remaining propulsion system is the monopropellant RCS, whose orbit maneuver capability is far limited compared with OME. Though the plan of perihelion maneuvers to reencounter Venus was basically unchanged, the Venus orbit injection plan needed to be changed substantially. Not only that finally attainable orbit turns into much larger elliptical orbit, but also VOI sequence is changed in order to avoid the undesirable influence of solar perturbation. Details of these topics are introduced in the following sections.

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Though the attempt of VOI was failed, the state of AKATSUKI seems well except for its OME. Besides, OME showed the thrust 75% of its full performance at the end of the injection maneuver, and 80% of propellant remained on board. These facts suggested the possibility to perform orbit maneuvers to reencounter Venus and retry VOI.

Under this situation, the study was started on orbit plans toward VRE and VOI. The study was conducted step by step, which is introduced in this section. First, the chart so called "pericenter – apocenter graph" is used to establish basic strategy toward VRE. The use of 8:9 Venus resonant orbit was resolved, which moved forward the date of VRE (T_{VRE}) to November, 2015 without any increase of necessary velocity increment (Δv). The new T_{VRE} is about one year earlier than that expected from free orbit propagation. Then, concrete orbit maneuver sequence was studied using two body model. A number of orbit transfer types and sets of parameters were investigated, and evaluated from the point of necessary Δv and other practical factors. As a result, a perihelion maneuver (PHM) is scheduled in autumn 2011, around the second perihelion passage after the VOI failure, to reencounter the Venus. Finally, the sequence is brushed up using full model. The result obtained in the two body model worked well as an initial estimate, however, slight shift of the schedule and slight reduction of necessary Δv was resulted from the detailed study. Details of these topics are introduced in the following sub-sections.

Preliminary Analysis on Reencounter Strategy

Preliminary analysis is performed using the chart so called "pericenter – apocenter graph" (Figure 2). The initial orbit of AKATSUKI (a set of aphelion/perihelion radiuses) after the VOI failure is shown as the mark labeled "initial" at the right-bottom corner of the chart. The contours of excessive velocity (v_∞) at VRE indicate that v_∞ (or injection Δv (Δv_{inj})) decreases as the aphelion radius of the transfer orbit decreases. It means that, even if a deceleration maneuver at perihelion costs 230m/s to decrease the aphelion radius to be tangent to the orbit of Venus (to the mark labeled "target" at the left-bottom corner), it is paid back by the decrease of Δv_{inj} of the same amount. Though the total amount of Δv (Δv_{tot}) required for the "target" orbit is almost the same as that of the "initial" orbit, there are two obvious merits in the target orbit. First, Δv required for VOI, which is the most critical operation, is smaller than that of the initial orbit. To clarify the second merit, we have to remark that the target orbit has 8:9 resonance with Venus. That is, if AKATSUKI is injected into the target orbit immediately, it will reencounter Venus eight Venus years after the VOI failure. T_{VRE} in this case is November, 2015, which is about one year earlier than that expected from free orbit propagation. As a result, the use of 8:9 VSO was decided, which moved forward the VRE to November, 2015 without any increase of necessary velocity increment (Δv).

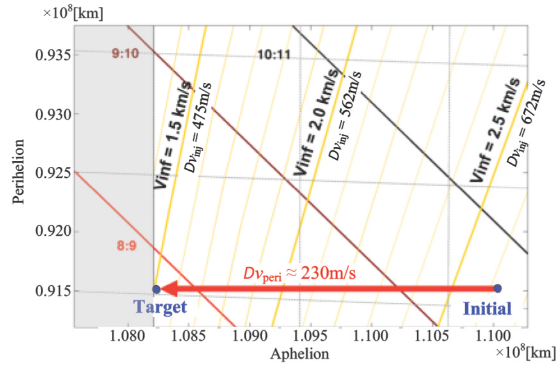


Figure 2. Preliminary Analysis on Reencounter Strategy.

Sequence Design under Two Body Model

The analysis in the previous sub-section provides useful insight to the characteristics of the problem. However, in order to construct a concrete orbit maneuver sequence, a sort of orbit design is necessary. Then, a two impulse transfer in a two body model, that is, a Lambert problem is used as the first step of the sequence design. Though it is a simple ballistic orbit design problem, the transfer assumes multiple revolutions around the Sun, and the problem has a number of local minimums. It is important to understand the structure of the solution space, and find a good initial guess of the solution prior to seeking accurate solutions by numerical methods. To this objective, theoretically established two body model is more advantageous than full model introduced in the next sub-section.

The result of the analysis in the previous sub-section defines a couple of orbit design conditions. First, as a result of adopting 8:9 VSO, T_{VRE} is set around November, 2015. Second, the transition from the initial orbit to the transfer orbit is achieved by PHM in order to lower the apohelion of the orbit. Accordingly, the chance of the first maneuver is limited to the date around perihelion passages. Additionally, an immediate transition to transfer orbit is necessary to achieve 8:9 VSO with small Δv. It requires the first maneuver to be performed in the early phase of the transfer. Based on these conditions, three types of transfer sequence, Type I to III, are defined in this study (Figure 3). They are typified by the range of PHM date (T_{PHM}), the range of T_{VRE}, and the number of revolutions from PHM to VRE (n_{rev}). For example, a transfer sequence in Type I has T_{PHM} around the first perihelion passage (i.e. April, 2011), T_{VRE} around November, 2012, and n_{rev} of eight.

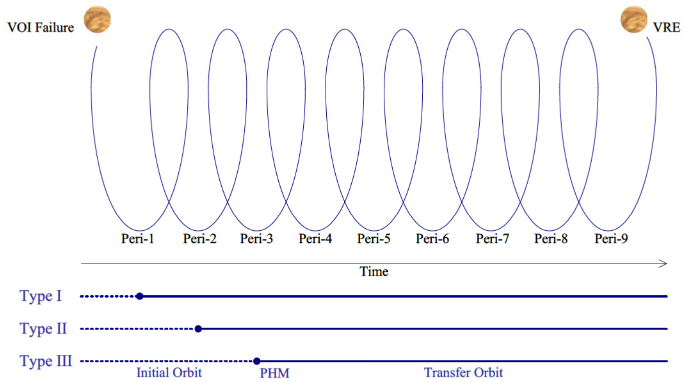


Figure 3. Schematics of Transfer Types.

Even if the three design parameters (T_{PHM} , T_{VRE}, n_{rev}) are assigned, a multi revolution Lambert problem still has two solutions.[1] Both solutions comply with the three parameters, however, they have different semi-major axes (a). Figure 4 shows an example of the two solutions for the same parameters. The parameters are chosen from the range of the Type I (T_{PHM} = April 24, 2011, T_{PHM} = Nov. 20, 2015, n_{rev} = 8). Though the two orbits (orange and green) have the same T_{PHM} , T_{VRE}, and n_{rev}, the shape of the orbits are quite different. Hereafter, these two sub-types of the orbit are distinguished by superscripts '+' (for larger a) and '-' (for smaller a) such as Type I^{+} and Type I^{-}.

Figure 4 shows Δv_{tot} level sets with respect to T_{PHM} and T_{VRE} of Type I^{+} and Type I^{-}. They are produced independently (since the formulation of Lambert's problem is different), and the ranges around their respective local minimum are focused. Though the both types have their local minimum in the range of Type I (i.e. T_{PHM} around April, 2011, and T_{VRE} around November 2015), they are apparently independent. Considering that they have close value of Δv_{tot} (788.6m/s and 813.9m/s respectively), the two minimums have to be found out and evaluated in the detailed design as well.

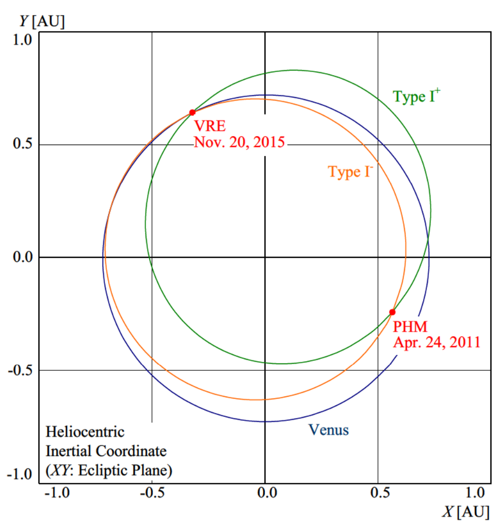
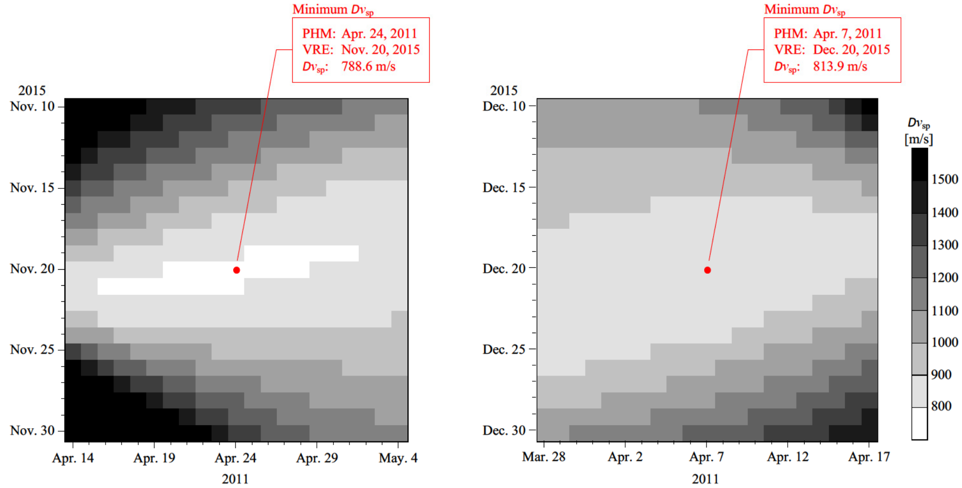


Figure 4. Two Solutions of Lambert Problem.



(a) Type I$^-$ (b) Type I$^+$

Figure 5. ***Dv*** **Level Sets of Two Lambert Solution Types.**

Two impulse transfer orbits are constructed for all the combination of T_{PHM} and T_{VRE} in each type. Δv_{tot} is evaluated for each case and the local minimum of Δv_{tot} is specified for each type. The list of local minimums is shown in Table 1. First observation is that, for all types (Type I to III), the minimum of sub-type '-' provides smaller Δv_{tot} compared with sub-type '+'. Hence, within a type in this range, the adoption of sub-type '-' looks better (The superiority of sub-type '-' is reconfirmed in the following detailed analysis). Then, in the comparison between Type I$^-$ to III$^-$, the type with earlier T_{PHM} (Type I$^-$) provides smaller Δv_{tot} compared with later T_{PHM} (Type III$^-$). This tendency complies with our prospect that the earlier transition to transfer orbit will save Δv to achieve 8:9 VSO. However, we paid attention to the fact that the difference of Δv_{tot} between Type I- and II- is so small that we can take other aspects into account to decide the baseline sequence. In actual, the schedule of OME ground tests (to find out the operation condition under malfunction) is so tight to perform the first maneuver at the first perihelion passage (April, 2011). As a result, a perihelion maneuver (PHM) is scheduled in autumn 2011, around the second perihelion passage after the VOI failure, to reencounter the Venus.

Table 1. Minimum ***Dv*** **Solutions under Two Body Model.**

Type	PHM		VRE		Dv_{sp}
	date	Dv_{peri}	date	Dv_{inj} (*)	
I$^-$	Apr. 24, 2011	230.7m/s	Nov. 20, 2015	557.9m/s	788.6m/s
I$^+$	Apr. 7, 2011	262.0m/s	Dec. 20, 2015	551.9m/s	813.9m/s
II$^-$	Nov. 12, 2011	269.1m/s	Nov. 24, 2015	523.1m/s	792.2m/s
II$^+$	Oct. 27, 2011	290.4m/s	Dec. 17, 2015	522.9m/s	813.3m/s
III$^-$	Jun. 10, 2012	320.7m/s	Nov. 30, 2015	489.3m/s	810.0m/s
III$^+$	May 15, 2012	322.8m/s	Dec. 12, 2015	492.7m/s	815.5m/s

(*) Venus Reencounter *Dv* assumes injection into 30h orbit.

Trajectory Design under Multi Body Model

Finally, the sequence is brushed up using full model. In contrast with the two body model, there is no difference between types or sub-types in the formulation of full model analysis. From this point, to provide a good initial guess is necessary to obtain the solution in mind. The result obtained by two body model is used for this objective. That is, for each set of T_{PHM} and T_{VRE}, Δv_{PHM} obtained in the two body model is used as the initial guess to find out the solution of the type in intention. This procedure works well, and all the local minimums are successfully found in the full model as well.

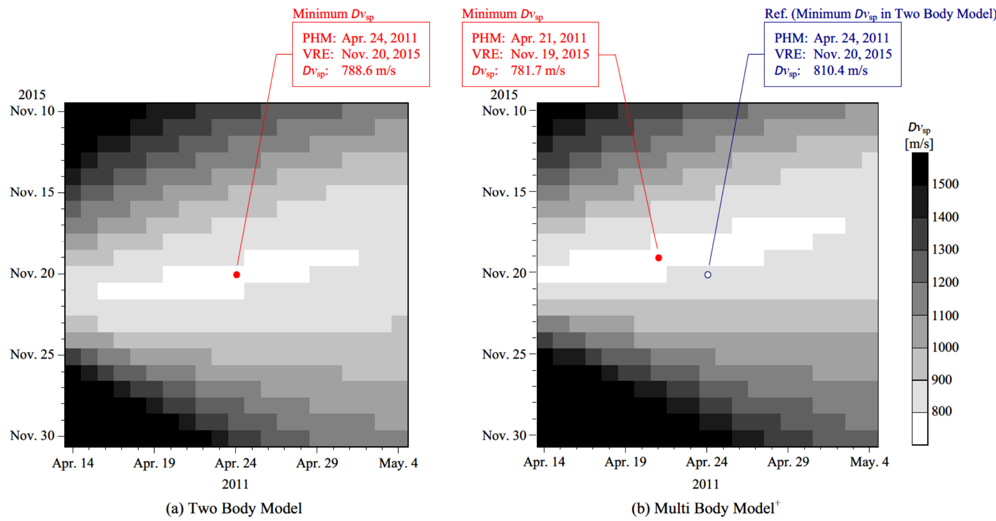


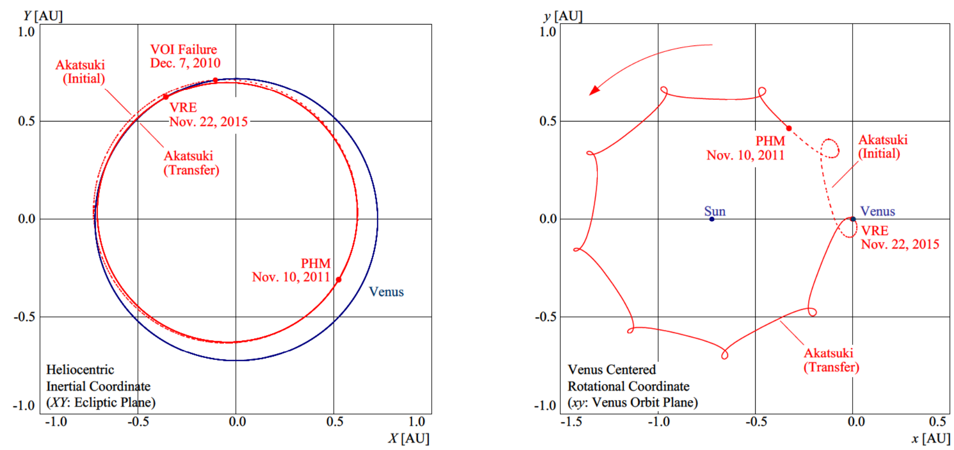
Figure 6. *Dv* Level Sets under Two Body / Multi Body Model (Type I⁻)

Figure 6 shows Δv_{tot} level sets with respect to T_{PHM} and T_{VRE} of Type I^-, constructed by two body model and full model respectively. Obviously, the solution space holds its basic structure which means that the Type I^- solutions are successfully found in the full model as well. The local minimum in the full model is provided by the set of T_{PHM} and T_{VRE} in the neighbor of the set provides the minimum in the two body model. This fact suggests that even if we use the convergence process to find the local minimum in the full model, the results obtained in the two body model provide good initial guess of the set of T_{PHM} and T_{VRE}. On the other hand, Δv_{tot} for the same set of T_{PHM} and T_{VRE} differs seriously between the two body model and the full model. For example, Δv_{tot} for T_{PHM} = Apr. 24, 2011, T_{VRE} = Nov. 20, 2015 are 788.6m/s and 810.4m/s in the two models respectively. This fact suggests that the set of T_{PHM} and T_{VRE} which provides the minimum Δv_{tot} in the two body model cannot be used directly as the set to provide the minimum Δv_{tot} in the full model.

Table 2. Minimum *Dv* Solutions under Multi Body Model.

Type	PHM		VRE		Dv_{sp}
	date	Dv_{peri}	date	Dv_{inj} (*)	
I^-	Apr. 21, 2011	226.5m/s	Nov. 19, 2015	555.2m/s	781.7m/s
I^+	Apr. 6, 2011	251.3m/s	Dec. 19, 2015	554.1m/s	805.4m/s
II^-	Nov. 10, 2011	261.4m/s	Nov. 22, 2015	522.0m/s	783.4m/s
II^+	Oct. 21, 2011	283.4m/s	Dec. 17, 2015	529.9m/s	813.3m/s
III^-	Jun. 6, 2012	314.1m/s	Nov. 28, 2015	481.0m/s	795.0m/s
III^+	May 17, 2012	319.2m/s	Dec. 9, 2015	484.5m/s	803.6m/s

(*) Venus Reencounter *Dv* assumes injection into 30h orbit.



(a) Heliocentric Inertial Frame.

(b) Venus Centered Rotational Frame.

Figure 7. An Orbit Plan of AKATSUKI towardVenus Reencounter

Two impulse transfer orbits are constructed under full model for all the combination of T_{PHM} and T_{VRE} in each type. Δv_{tot} is evaluated for each case and the local minimum of Δv_{tot} is specified for each type. The list of local minimums is shown in Table 2. When the list is compared by type by type with that made under two body model (Table 1), slight shift of the schedule and slight change of Δv_{tot} are observed. However, the basic characteristics derived under the two body model still holds in the results obtained in the full model. That is, the minimum of sub-type '-' provides smaller Δv_{tot} compared with sub-type '+', and Type I^- and II^- provides smaller Δv_{tot} compared with Type III^-. Considering the practical aspects mentioned in the previous sub-section, the local minimum of Type II- transfer sequence is selected as the baseline trajectory sequence.

The orbit profile of the baseline sequence is shown in Figure 7. The initial orbit is drawn in dashed line whereas transfer orbit after PHM is drawn in solid line. The orbit profile drawn on the inertial frame (Figure 7 (a)) shows that PHM lowers the apohelion of the orbit so that the transfer orbit tangent with the Venus orbit nearby its apohelion. Hence VRE occurs around the apohelion of the orbit. In the orbit profile drawn on the rotational frame (Figure 7 (b)), there are a number of small circles along the path. They comply with the apohelion passages of AKATSUKI. If the figure is carefully compared with Figure 1 (b), it is found that the number of apohelion passage by VRE reduced to nine (from eleven), and the stroke between the circles slightly gets longer due to the increase of relative orbit velocity of AKATSUKI.

PERIHELION MANEUVER OPERATION RESULTS

Prior to its perihelion maneuver in November, 2011, test firings of OME were performed in September, 2011. Unfortunately, the test results show that the thrust of OME is far lower than expected, which forced us to give up using the OME in upcoming maneuvers. The remaining propulsion system is the monopropellant RCS, whose orbit maneuver capability is far limited compared with OME.

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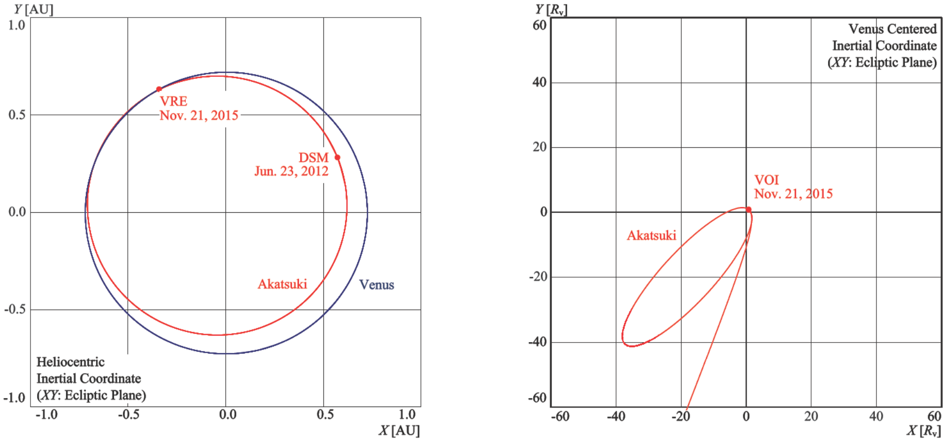
Now the only available propulsion system onboard is RCS. Though the performance (thrust and Isp) of RCS is lower than that of OME, it is estimated that it can inject AKATSUKI into the Venus orbit. However, the resulting orbit is highly elliptic which does not satisfy the original mission requirement any more. Moreover, the resulting orbit is strongly perturbed by the solar gravity due to its high apocenter.

Reported in this section is the study result of AKATSUKI's VOI sequence under this situation. First, a simple straightforward VOI sequence is introduced which assumes the injection at VRE in November, 2015. It is shown that the drop of pericenter due to the solar gravity perturbation is too fast to be accepted, when the injection into the low inclination orbit plane is assumed (which is the requirement from the science mission). To cope with this problem, the use of a Venus swingby (VSB) and a Venus synchronous orbit (VSO) is proposed. In this case, VOI is postponed by at least one Venus year. However, the approach direction to Venus is changed efficiently by VSB, which result in longer orbit life on Venus orbit. Details of these topics are introduced in the following sub-sections.

Venus Orbit Injection at the First Venus Reencounter

In spite of the serious degradation of the orbit maneuver capability, PHM was performed basically as it was planned in the previous section. Because the baseline sequence aims to set the final orbit altitude as low as possible, and this objective is still effective under this situation.

An orbit plan constructed based on the results of PHM shows that VRE in November, 2015 is still possible with a small deep space maneuver (DSM) on the way (Figure 8 (a)). In this case, 270.8m/s is allocated for Δv_{inj} which results in the apocenter radius of about 55 Venus radius (R_v) after injection. The argument of ballistic parameter (B_θ) is set to 0 deg. considering the requirement from the science mission to inject AKATSUKI into the orbit near to Venus equatorial plane (Figure 8 (b)). The spacecraft design, in particular the thermal design, is also optimized to the operation on the orbit near to Venus equatorial plane.

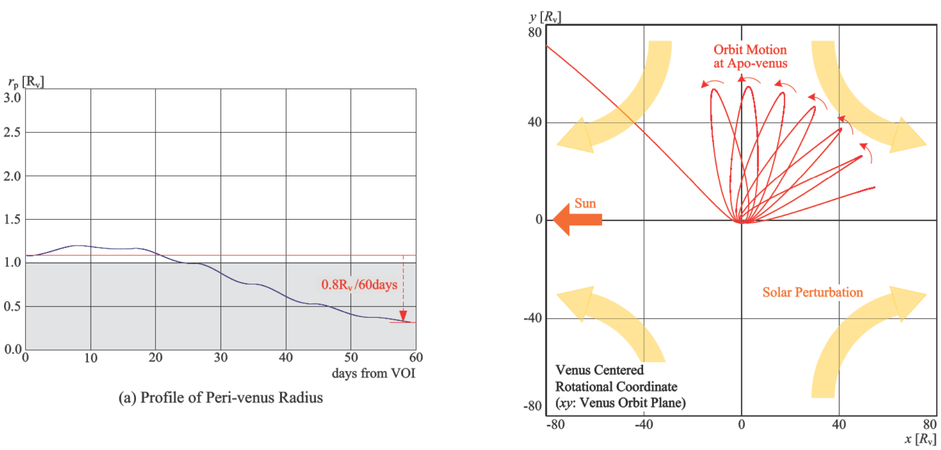


(a) Interplanetary Cruise. (b) Venus Approach and Orbit Injection.

Figure 8. An Orbit Plan of AKATSUKI towardVenus Reencounter and Orbit Injection (after Perihelion Maneuver)

However, there is a serious problem in this orbit. Because of the perturbation by the solar gravity, the pericenter altitude drops rapidly, and AKATSUKI crashes on the Venus surface within a month (Figure 9 (a)). The rate of altitude drop is about $0.8R_V$/60days. Apocenter Δv to compensate for this altitude drop is roughly estimated to be 70m/s, which is unacceptable under the serious propellant budget in this situation.

Figure 9 (b) clarifies the mechanism of this phenomena using the orbit profile drawn on the solar direction fixed rotational frame. AKATSUKI is injected into the orbit whose apocenter is in the direction of $+y$ axis at the beginning, and moves clockwise into the first quadrant due to the rotation of the frame. The orbit motion of AKATSUKI is counterclockwise in this case (B_θ = 0deg.), and the motion around the apocenter are expressed by red arrows. On the other hand, the perturbation force by the solar gravity works in the direction expressed by thick orange arrows. In the first quadrant, it works to decelerate the motion at apocenter, which results in the drop of pericenter altitude.



(a) Profile of Peri-venus Radius

(b) Effect of Solar Perturbation

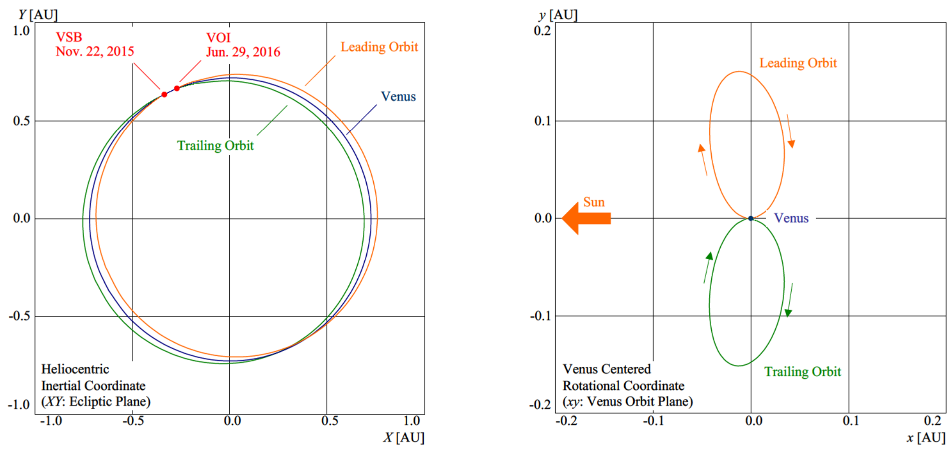
Figure 9. Drop of Peri-venus Radius under Solar Perturbation

It should be noted that this geometry holds in general when we adopt the sequence to minimize Δv_{tot}. In this case, the transfer orbit is designed to be approximately tangent to the Venus orbit, and AKATSUKI approaches Venus from the front side (or $+y$ axis direction in Figure 9 (b)). If B_θ = 0deg., the apocenter after the injection moves through the first quadrant of Figure 9 (b).

In addition, the situation does not change even if B_θ is set to 180 deg. In this case, the apocenter after the injection moves through the second quadrant of Figure 9 (b). The orbit motion of AKATSUKI is clockwise in this case (B_θ = 180deg.). Again, the perturbation force by the solar gravity works to decelerate the motion at apocenter, which results in the drop of pericenter altitude.

Usage of Venus Swingby to Supress the Pericenter Drop

As is clarified in the previous section, the pericenter drop mechanism holds in general if AKATSUKI approaches Venus from the front side. And this situation at VRE is inevitable as far as we aim to minimize Δv_{tot}. However, if we don't stick to inject AKATSUKI into the Venus orbit at the first VRE, there is a way to change the approach direction.



(a) Heliocentric Inertial Frame. (b) Venus Centered Rotational Frame.

Figure 10. Coplanar Venus Synchronous Orbits

Table 3. Sequence of Events for Coplanar Venus Synchronous Orbits

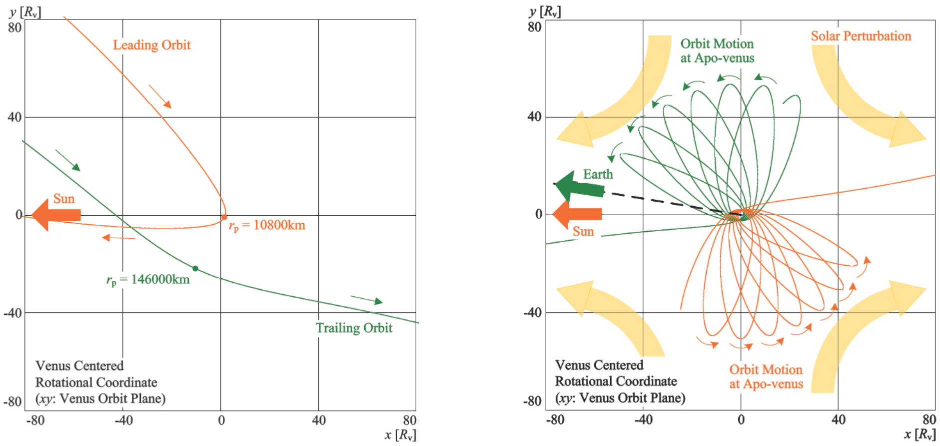
(a) Leading Orbit.

Date	Event	Dv	r_p	B_q
Nov. 22, 2015	Venus Swingby	–	10800km	180deg.
Jan. 8, 2016	Deep Space Maneuver	4.7m/s	–	–
Jun. 29, 2016	Venus Orbit Injection	278.6m/s	6552km	0deg.

(b) Trailing Orbit

Date	Event	Dv	r_p	B_q
Nov. 22, 2015	Venus Swingby	–	146000km	0deg.
Jan. 17, 2016	Deep Space Maneuver	5.2m/s	–	–
Jun. 29, 2016	Venus Orbit Injection	272.1m/s	6552km	0deg.

By use of VSB at the first VRE, it is possible to inject AKATSUKI into VSO (1:1 Venus resonant orbit). In order to inject AKATUKI into the orbit near to Venus equatorial plane in the end, VSO nearby the Venus orbit plane (named coplanar VSO hereafter) are of interest. There are two options of coplanar VSO depending on the direction of v_∞ at the Venus encounter. If v_∞ directs the Sun, AKATSUKI flies in the leading side of the Venus, and the orbit is called "leading orbit". On the contrary, if v_∞ directs the opposite of the Sun, AKATSUKI flies in the trailing side of the Venus, and the orbit is called "trailing orbit". Figure 10 shows the coplanar VSO connected with the first VRE of AKATSUKI. These orbits are realized by the sequence (including VSB condition) listed on Table 3.



(a) Venus Swingby

(b) Venus Orbit Injection and the Sequel

Figure 11. Change of Venus Approach Direction by way of Co-planar Venus Synchronous Orbit.

The important point is that, the approach direction to Venus in this case is approximately normal to the orbit velocity of Venus. As is shown in Figure 11, in case of the leading orbit (the orange line), AKATSUKI escapes toward -x direction of the solar direction fixed rotational frame at the first VRE (Figure 11 (a)), and approaches from +x direction at the second VRE (Figure 11 (b)). At the second VRE, AKATSUKI is injected into the orbit whose apocenter is in the direction of +x axis at the beginning, and moves clockwise through the forth quadrant due to the rotation of the frame. The orbit motion of AKATSUKI is counterclockwise in this case (B_θ = 0deg. at VOI), and the motion around the apocenter are expressed by small orange arrows. In this case, the perturbation force by the solar gravity works to accelerate the motion at apocenter, which results in the rise of pericenter altitude.

The same scenario holds in case of the trailing orbit (the green line) as well. Though the escape/approach direction at VRE is opposite to that of the leading orbit, after all, the perturbation force by the solar gravity works to raise the pericenter altitude.

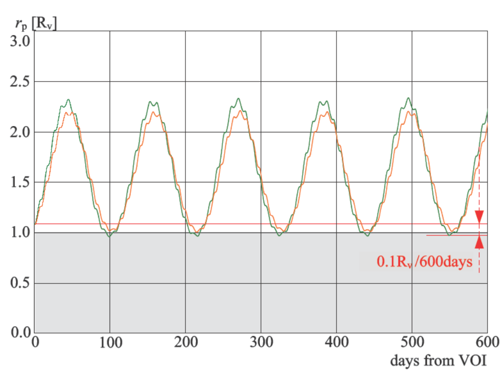


Figure 12. Peri-venus Radius Profile in case of 2016 Venus Orbit Injection

Figure 12 shows the profile of pericenter radius (r_p) after VOI. Note that the range of the horizontal axis (days from VOI) is far longer than that of Figure 9 (a). The minimum r_p is smaller than that at VOI by 0.1 R_v, and it can be compensated by 8m/s of apocenter Δv, which is acceptable in the propellant budget.

The essence of the difference between the case of “VOI at the first VRE” and “VOI after VSO” is summarized as follows. If the orbit profile of the leading orbit case (the orange line) in Figure 11 (b) is extended, the apocenter continues to move clockwise and go into the first quadrant. Since the direction of the perturbation force by the solar gravity is opposite to the motion at the apocenter, the pericenter drops when the apocenter is in this quadrant. Then, the pericenter drops when the apocenter is in the third quadrant, and the pericenter rise when the apocenter is in the fourth quadrant. This profile is observed as the oscillation of r_v in Figure 12. In the same way, r_v oscillates in case of “VOI at the first VRE” (though r_v seems to drop monotonically due to the short time range). Then, the difference is in that, r_v profile starts at the top of the oscillation in the case of “VOI at the first VRE” whereas that starts at the bottom of the oscillation in the case of “VOI after VSO”.

Finally, the comparison between “leading orbit” and “trailing orbit” is briefly noted. First, there is no significant difference in Δv_{tot} (Table 3) and r_v profile (Figure 12). Second, to look at the orbit profile at VSB (Figure 11 (a)), the swingby radius of the trailing orbit case is larger than that of the leading orbit case. It suggests that the trailing orbit case is robust to the orbit error at VSB, and Δv for the correction maneuver is expected to be suppressed. Third, to look at the orbit profile at VOI (Figure 11 (b)), the arc at VOI of the trailing orbit case is occulted by Venus whereas that of the leading orbit case is visible from the Earth all along.

Detailed trade off between the sequences introduced in this section is still continued.

CONCLUSION

Discussed in this paper is an orbit plan toward AKATSUKI’s Venus reencounter and orbit injection. The construction process of the baseline sequence toward the Venus reencounter is introduced in detail, and the sequence options of the Venus orbit injection are introduced. The perihelion maneuver was successfully completed in November, 2011, and AKATUSKI is now on the way to reencounter the Venus in November, 2015. Detailed trade off about the VOI sequence is still continued to maximize the science output and minimize the risk.